Webinar FAO/Agreenium/UN-ESCAP
October 28, 2020

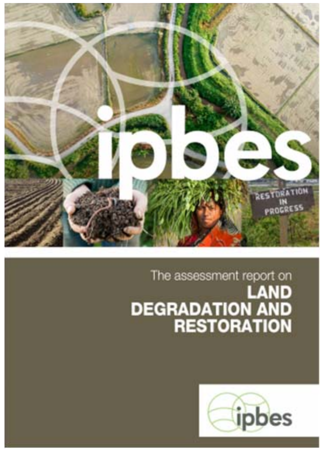
Preventing and mitigating land degradation: nutrient turnover and terrestrial carbon sequestration

Agricultural and forestry strategies to prevent and mitigate land degradation, with a special focus on nutrient turnover and carbon sequestration

Dr. Julien Demenois (Cirad)

cirad
AGRICULTURAL RESEARCH FOR DEVELOPMENT

1. What is land degradation? What is the extent of land degradation and what are the challenges?
2. Potential strategies in agriculture and forestry to prevent and mitigate land degradation
3. A focus on agroforestry in DR Congo to contribute positively to nutrient turnover and carbon sequestration



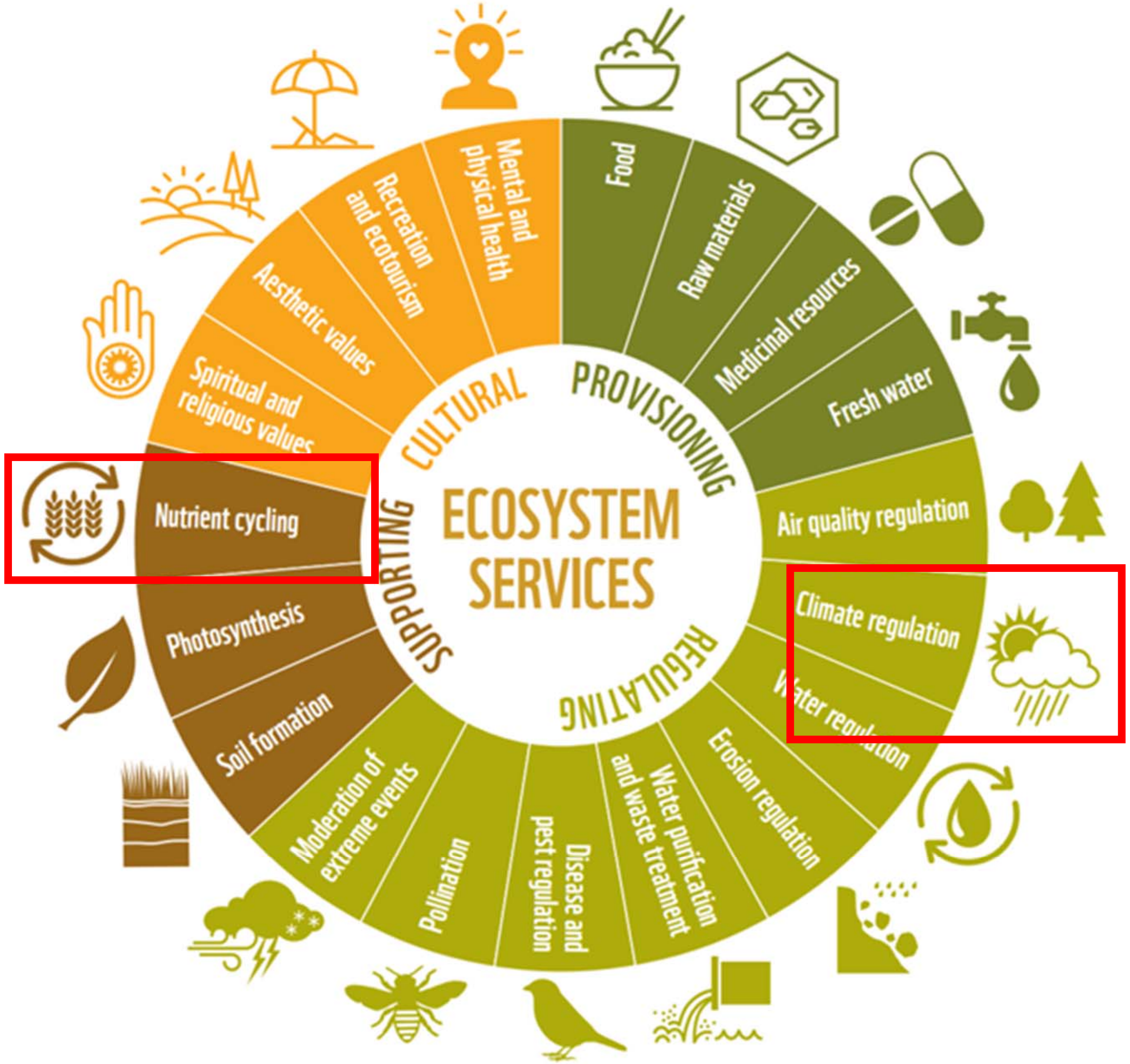
What is land degradation ?

Land degradation
Refers to the many processes that drive the **decline or loss in biodiversity, ecosystem functions or services** and includes the degradation of **all terrestrial ecosystems**. (IPBES, 2019)

Biodiversity
The **variability** among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes **diversity within species, between species and of ecosystems**. (IPBES, 2019)

Ecosystem function(s)
The flow of energy and materials through the biotic and abiotic components of an ecosystem. It includes many processes such as **biomass production**, trophic transfer through plants and animals, **nutrient cycling**, water dynamics and heat transfer. (IPBES, 2019)

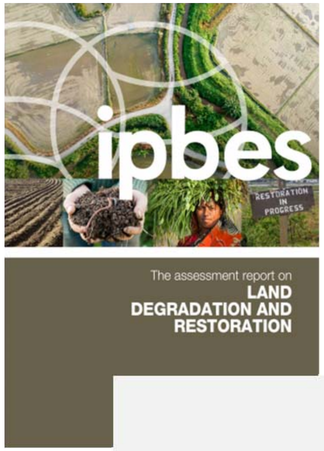
Ecosystem services
The benefits **people** obtain from ecosystems. In the Millennium Ecosystem Assessment, ecosystem services can be divided into **supporting, regulating, provisioning and cultural**. (IPBES, 2019)



ECOSYSTEM SERVICES

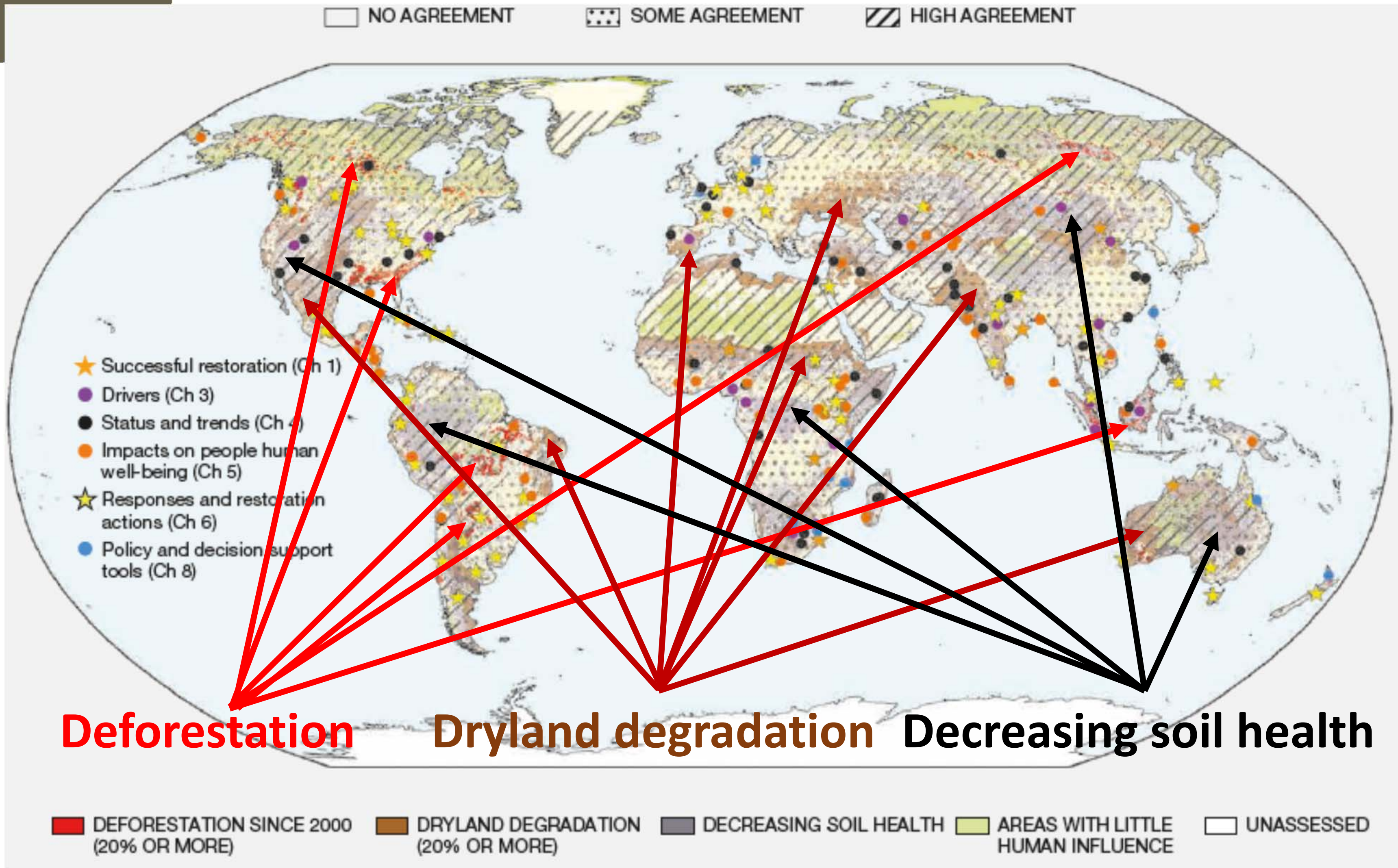
Provisioning services are the products obtained from ecosystems.
Regulating services are the benefits obtained from the regulation of ecosystem processes.
Cultural services are the nonmaterial benefits people obtain from ecosystems.
Supporting services are those services that are necessary for the production of all other ecosystem services.

Source *WWF Living Planet Report 2016, adapted from the Millennium Ecosystem Assessment 2005.*



What is the extent of land degradation and what are the challenges ?

Land degradation is a pervasive, systemic phenomenon: it occurs in all parts of the terrestrial world and can take many forms. (IPBES, 2019)

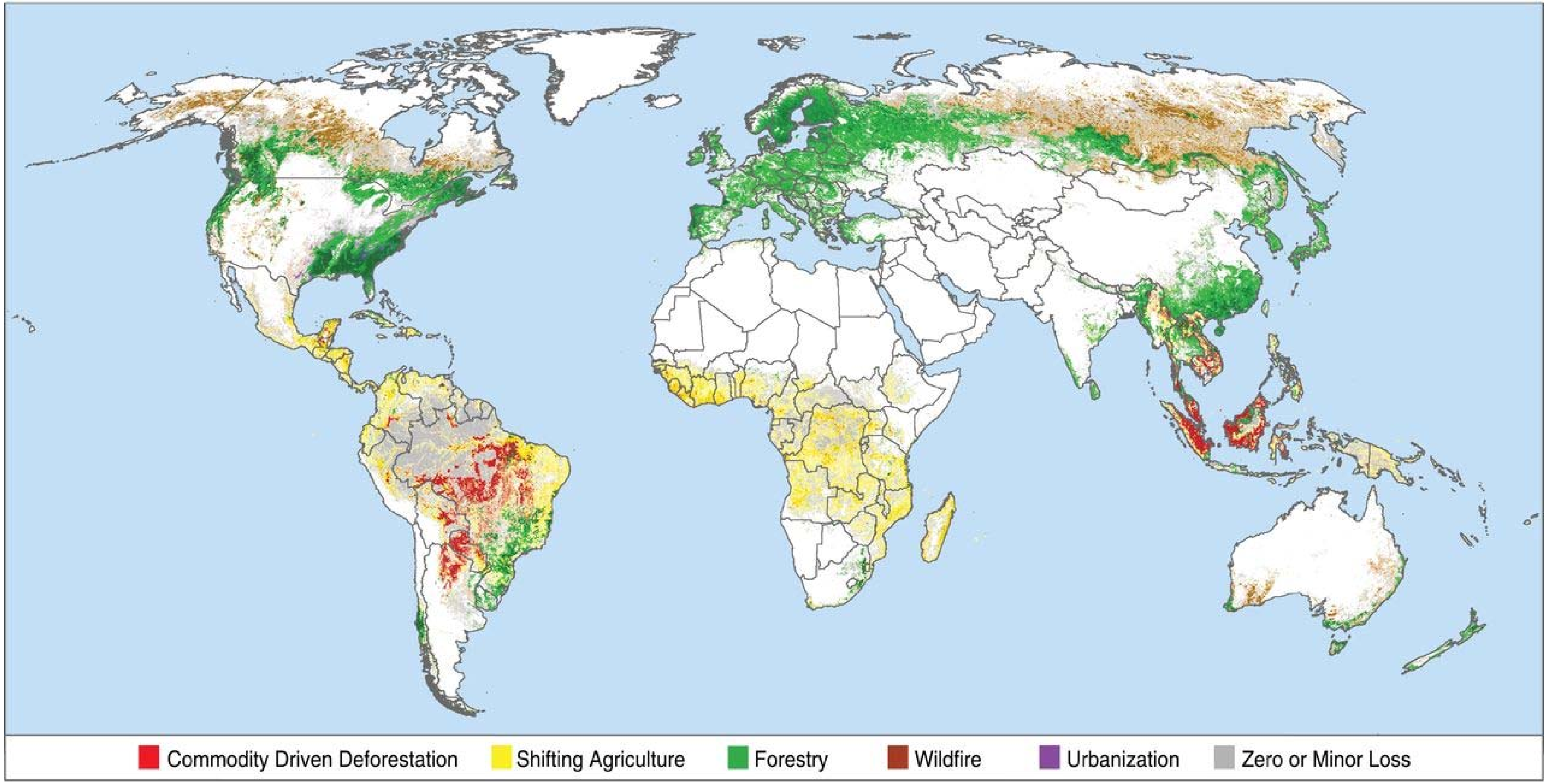


Forest degradation and deforestation

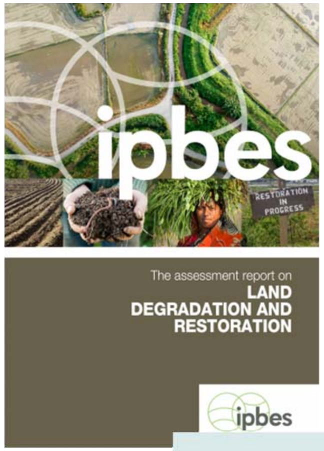
Science
AAAS

- rate of deforestation since 2001 : 5 Mha $year^{-1}$
- 1.5 GtC/year (Global Carbon Budget 2019)
- 14 % of CO_2 emissions

Primary drivers of forest cover loss for the period 2001 to 2015



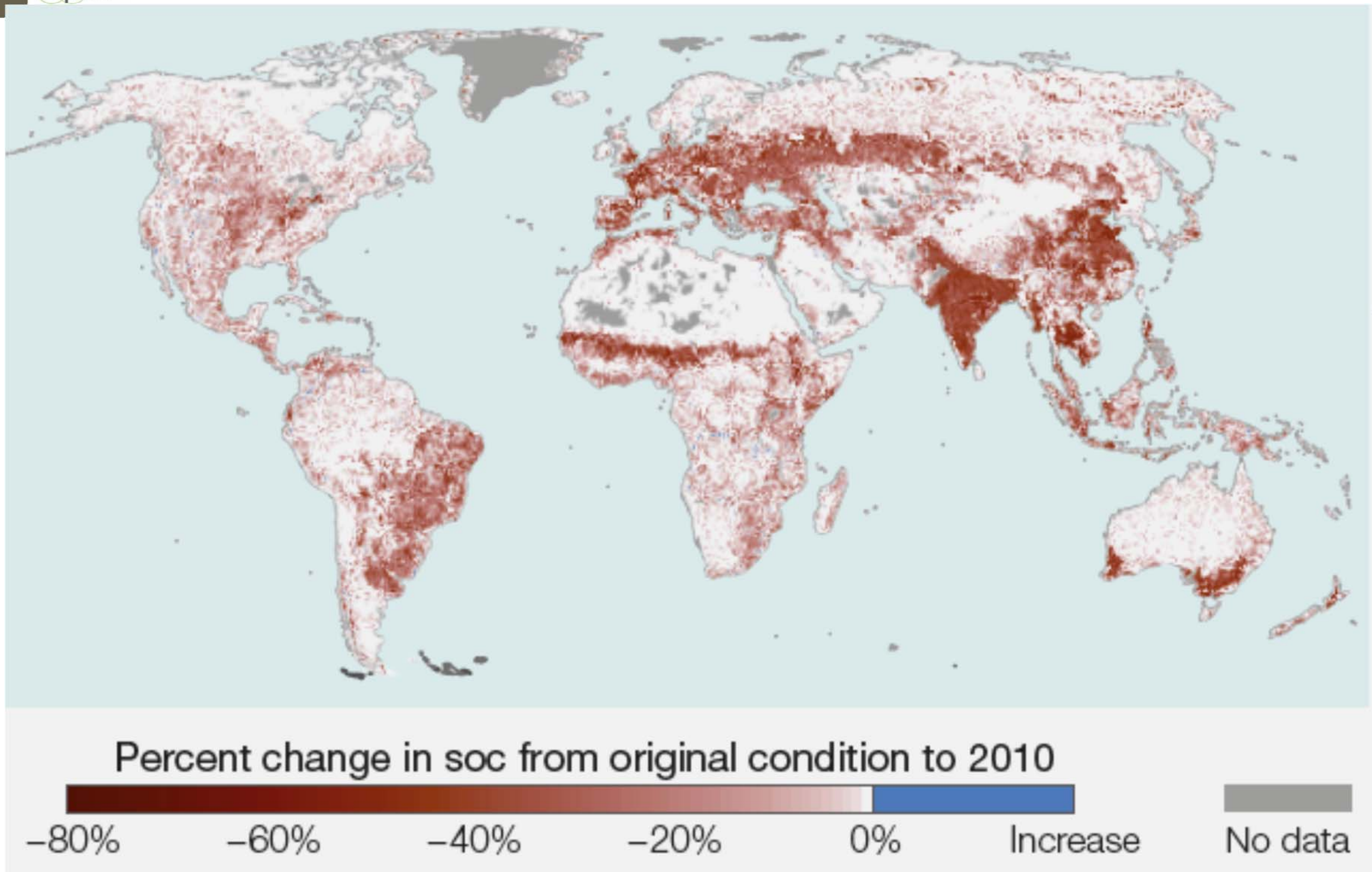
Philip G. Curtis et al. Science 2018;361:1108-1111



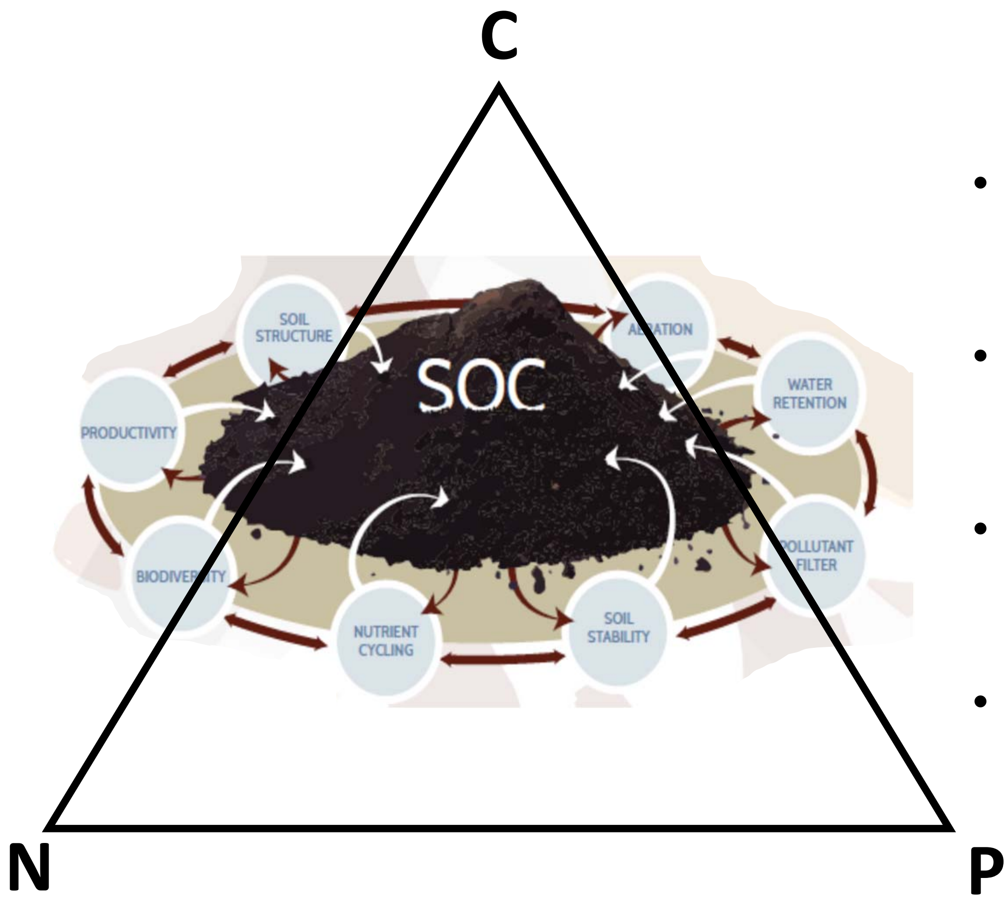
Soil health degradation

Change in Soil Organic Carbon (SOC) :

- 8 % loss over the two last centuries
- 176 GtC released
- 33 % of soils are moderately to highly degraded

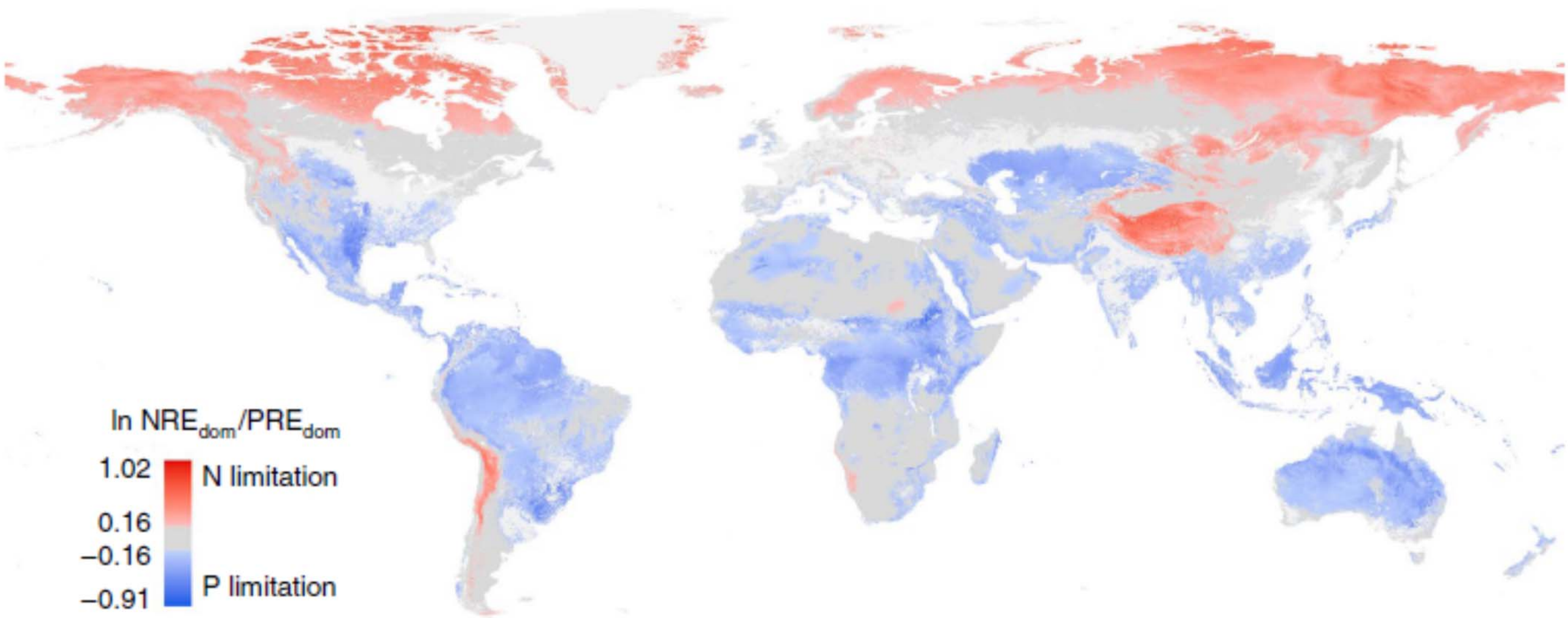


SOC, N and P linkages



- Carbon is the main component (more than 58%) of soil organic matter (SOM)
- C is strongly coupled to nutrients such as N and P
- N and P show constant ratios to C in a wide range of global soils
- The availability of nutrients, in particular N and P, is needed to achieve SOC stock increases

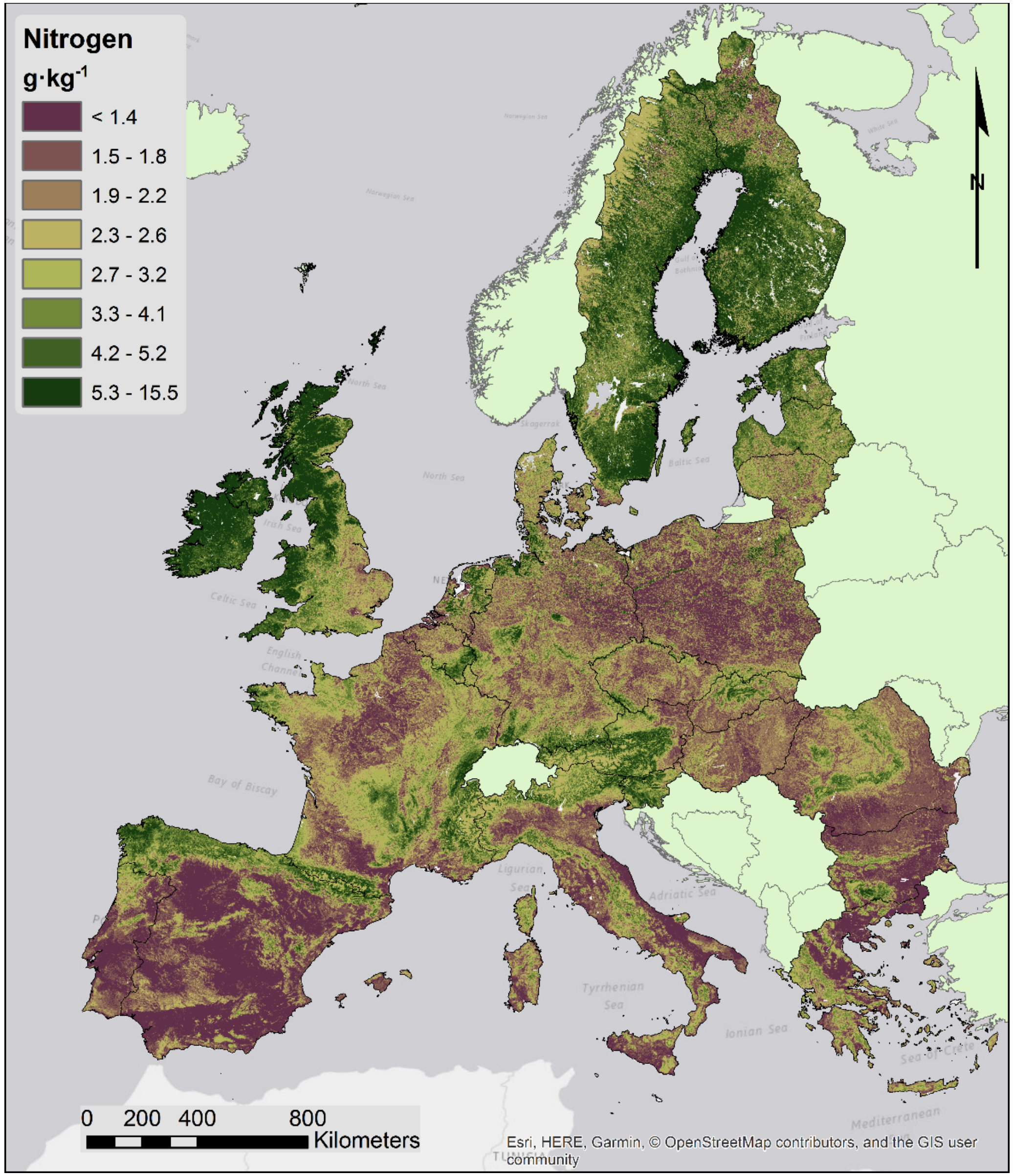
N and P limitations of terrestrial C uptake



- 18 % of natural terrestrial land area is limited by N
- 43 % of natural terrestrial land area is limited by P

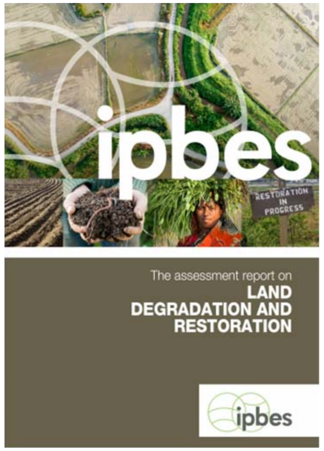
Du et al., 2020

N in Europe

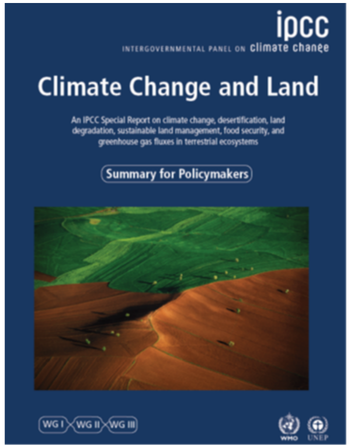


- N leaching
- Eutrophication of aquatic ecosystems

JRC, 2019



What is the extent of land degradation and what are the challenges ?

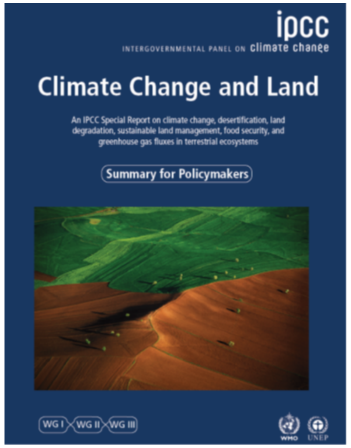


- The well-being of (at least) **3.2 billion people negatively impacted** by land degradation

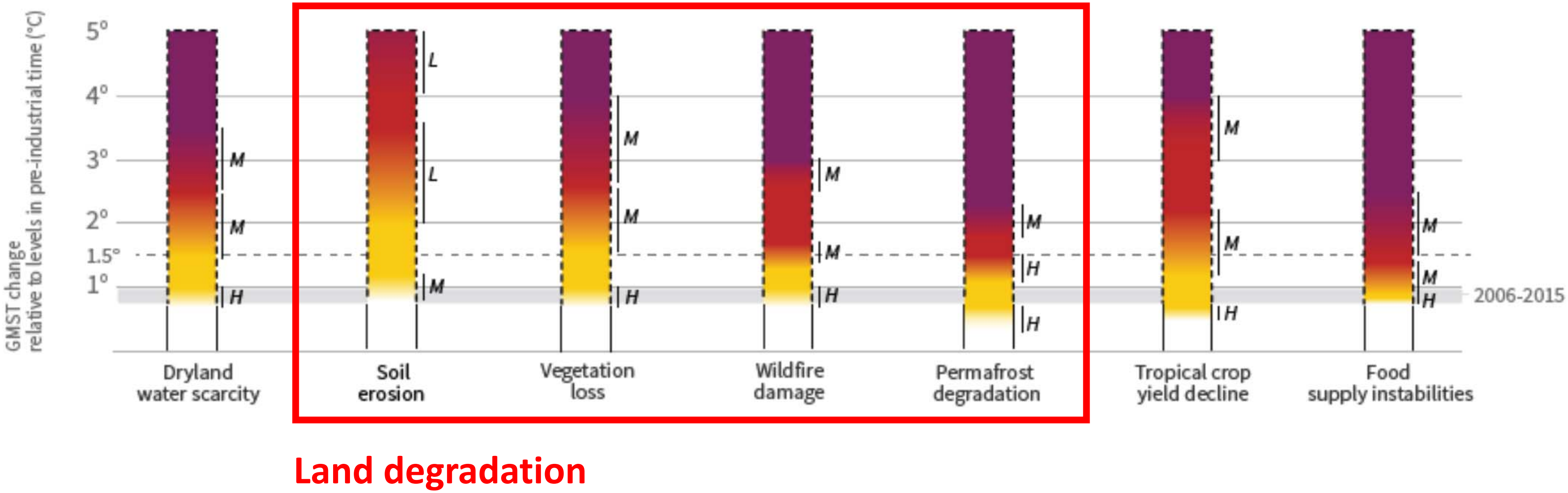
- Land degradation costs more than **10 per cent of the annual global gross product** in loss of biodiversity and ecosystem services

- **Climate change exacerbates land degradation**, particularly in low-lying coastal areas, river deltas, drylands and in permafrost areas (high confidence).

- The impact of almost all direct drivers of land degradation will be **worsened by climate change**. These include, among others, accelerated **soil erosion** on degraded lands as a result of more extreme weather events, increased risk of **forest fires** and changes in the distribution of invasive species, pests and pathogens.

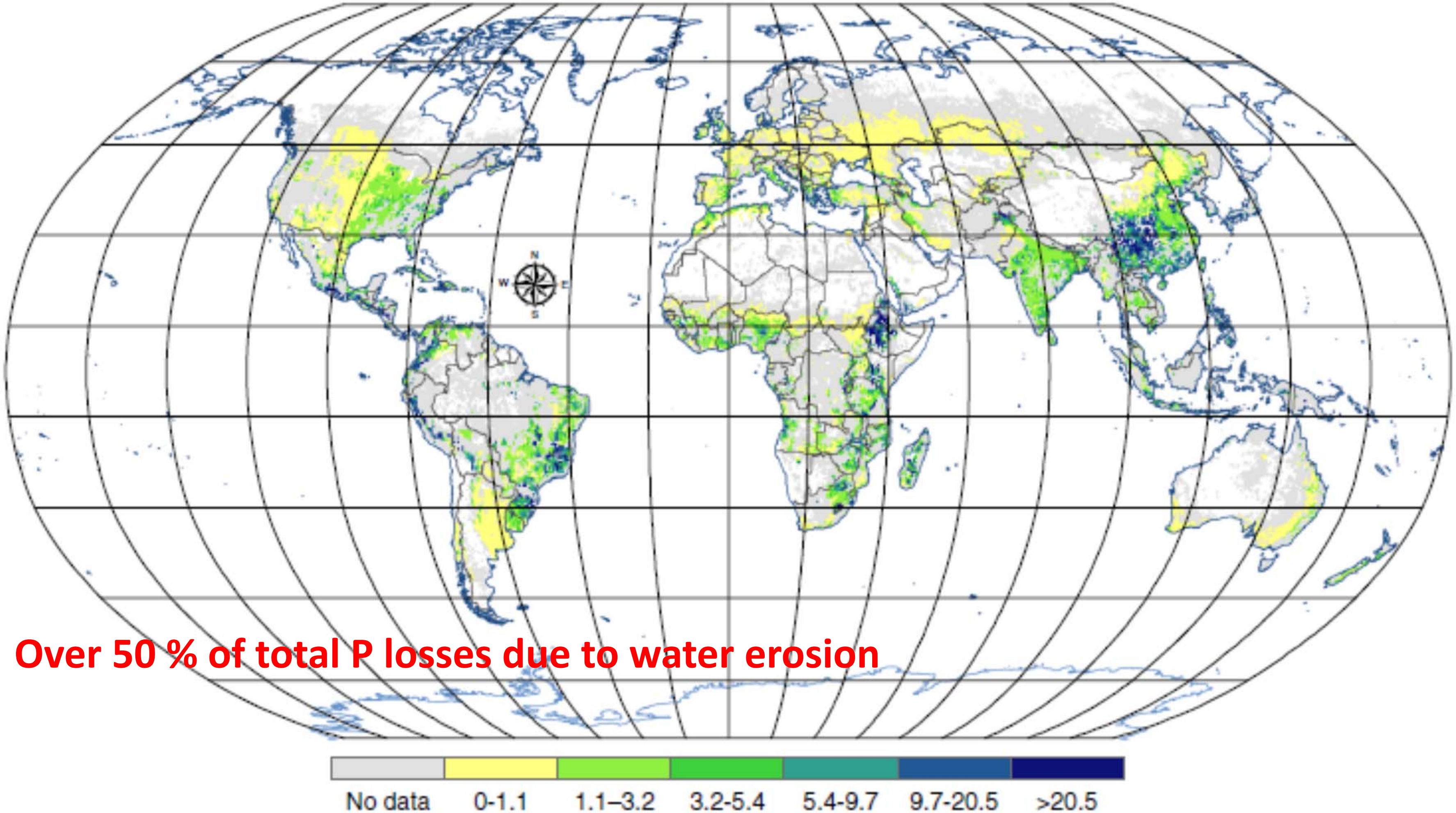


Climate change and land degradation



IPCC, 2019

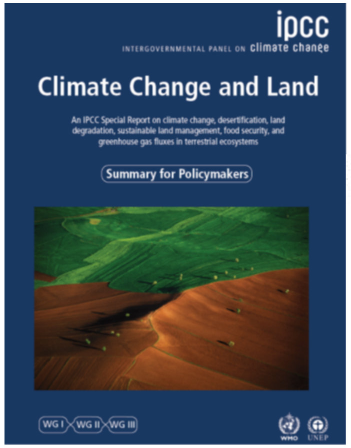
The Phosphorus challenge exacerbated by climate change



- **Over 50 % of total P losses due to water erosion**

Fig. 2 Global average phosphorus (P) losses due to soil erosion in kg ha^{-1} yr^{-1}. The chromatic scale represents the P losses estimates, while the gray color indicates the cropland areas that were excluded from the modeling due to data unavailability. Note that classes are not regularly scale ranked but are divided into six classes using the quantile classification method. Only plant available fractions were considered. For the more residual P fractions please refer to Table 1 or Figs. 3 and 4).

Alewell et al., 2020



IPCC, 2019

Climate change and land degradation

	Response options based on land management	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Cost
Agriculture	Increased food productivity	L	M	L	M	H	—
	Agro-forestry	M	M	M	M	L	●
	Improved cropland management	M	L	L	L	L	●●
	Improved livestock management	M	L	L	L	L	●●●
	Agricultural diversification	L	L	L	M	L	●
	Improved grazing land management	M	L	L	L	L	—
	Integrated water management	L	L	L	L	L	●●
	Reduced grassland conversion to cropland	L	—	L	L	- L	●
Forests	Forest management	M	L	L	L	L	●●
	Reduced deforestation and forest degradation	H	L	L	L	L	●●
Soils	Increased soil organic carbon content	H	L	M	M	L	●●
	Reduced soil erosion	←→ L	L	M	M	L	●●
	Reduced soil salinization	—	L	L	L	L	●●
	Reduced soil compaction	—	L	—	L	L	●
Other ecosystems	Fire management	M	M	M	M	L	●
	Reduced landslides and natural hazards	L	L	L	L	L	—
	Reduced pollution including acidification	←→ M	M	L	L	L	—
	Restoration & reduced conversion of coastal wetlands	M	L	M	M	←→ L	—
	Restoration & reduced conversion of peatlands	M	—	na	M	- L	●

	Response options based on value chain management	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Cost
Demand	Reduced post-harvest losses	H	M	L	L	H	—
	Dietary change	H	—	L	H	H	—
	Reduced food waste (consumer or retailer)	H	—	L	M	M	—
Supply	Sustainable sourcing	—	L	—	L	L	—
	Improved food processing and retailing	L	L	—	—	L	—
	Improved energy use in food systems	L	L	—	—	L	—

	Response options based on risk management	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Cost
Risk	Livelihood diversification	[illegible]	L	—	L	L	—
	Management of urban sprawl	—	L	L	M	L	—
	Risk sharing instruments	←→ L	L	—	←→ L	L	●●

How to increase soil organic carbon ?

- **Increase C inputs in soil**

Agroforestry

Integrated management of soil fertility

Pasture management and grazing lands

Organic fertilizers

Water management

Conservation agriculture

Agroecology

- **Decrease C outputs through mineralization and C exports**

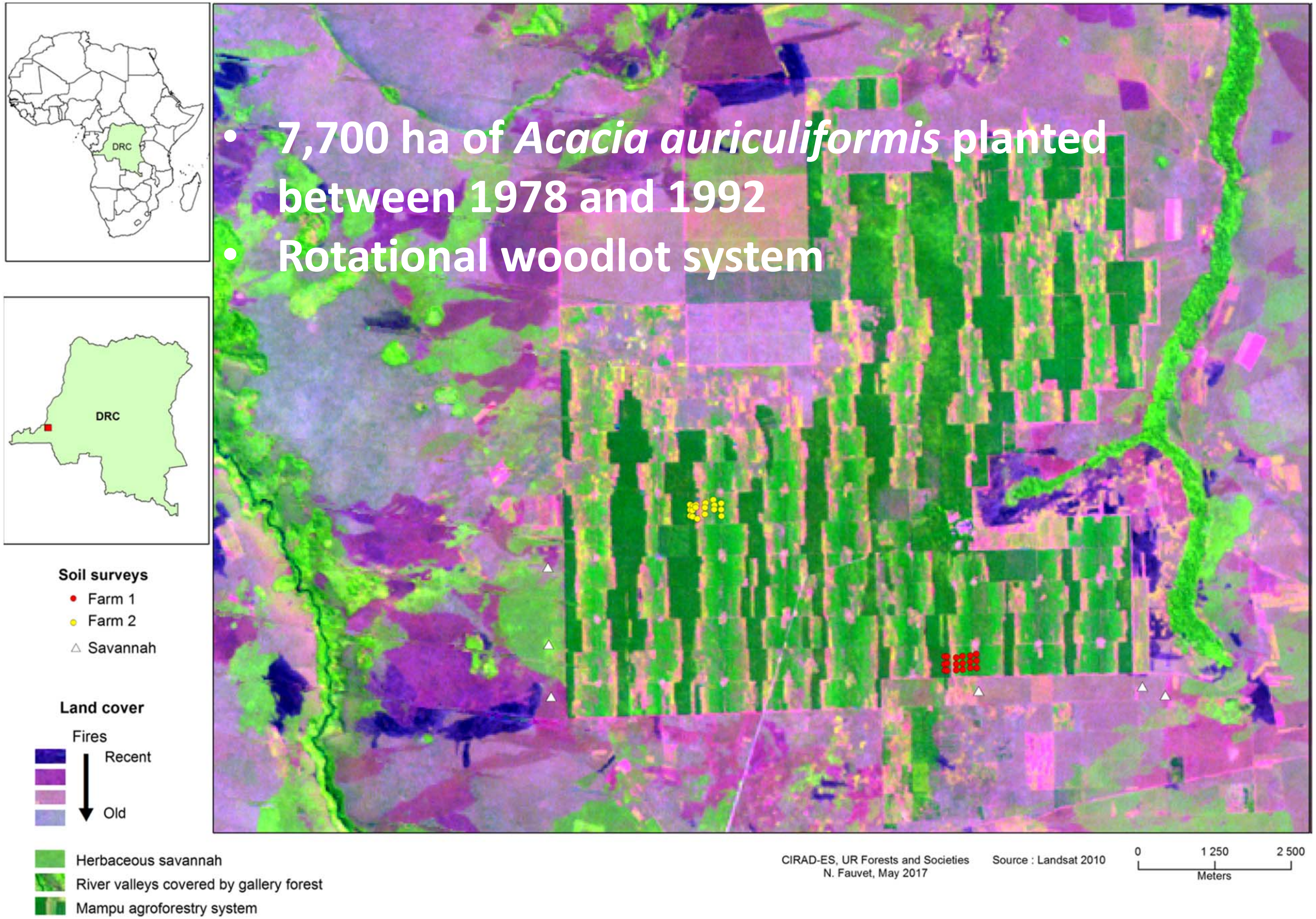
Fire management

Erosion control

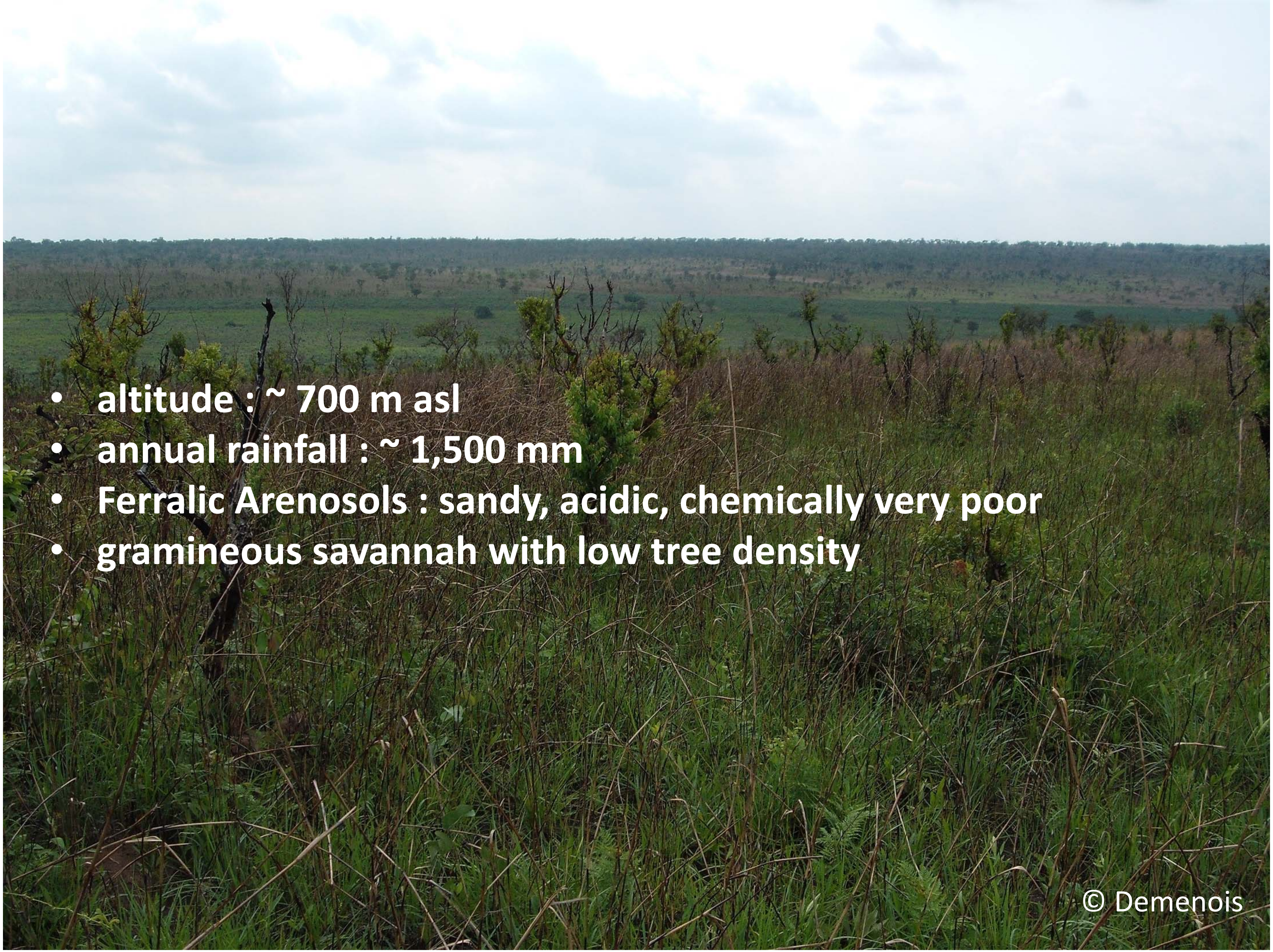
No tillage

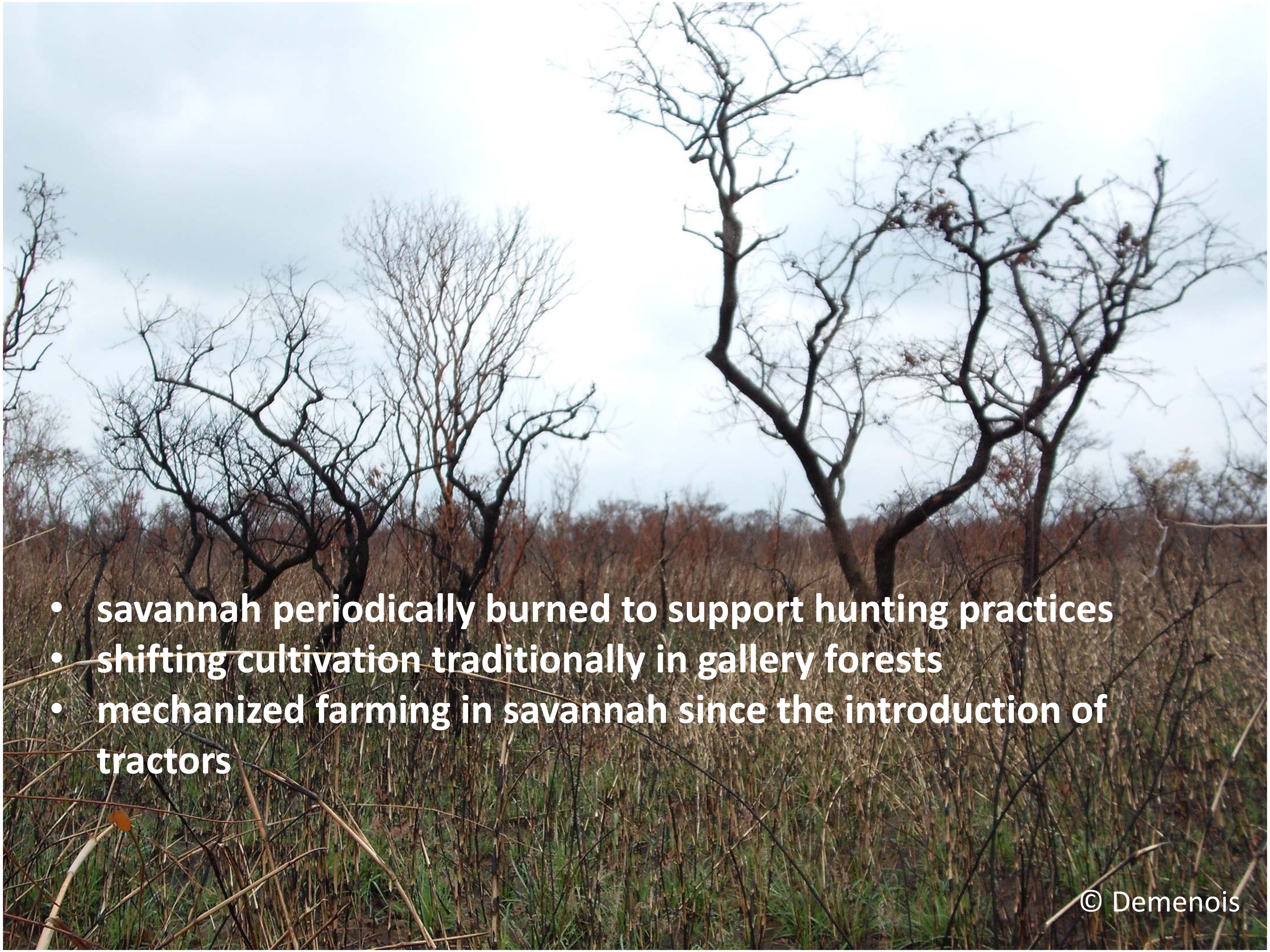
Agroforestry with N fixing trees on the Batéké Plateau in DR Congo

- 7,700 ha of *Acacia auriculiformis* planted between 1978 and 1992
- Rotational woodlot system



Dubiez et al, 2018


• altitude : ~ 700 m asl
• annual rainfall : ~ 1,500 mm
• Ferralic Arenosols : sandy, acidic, chemically very poor
• gramineous savannah with low tree density
© Demenois


• savannah periodically burned to support hunting practices
• shifting cultivation traditionally in gallery forests
• mechanized farming in savannah since the introduction of tractors
© Demenois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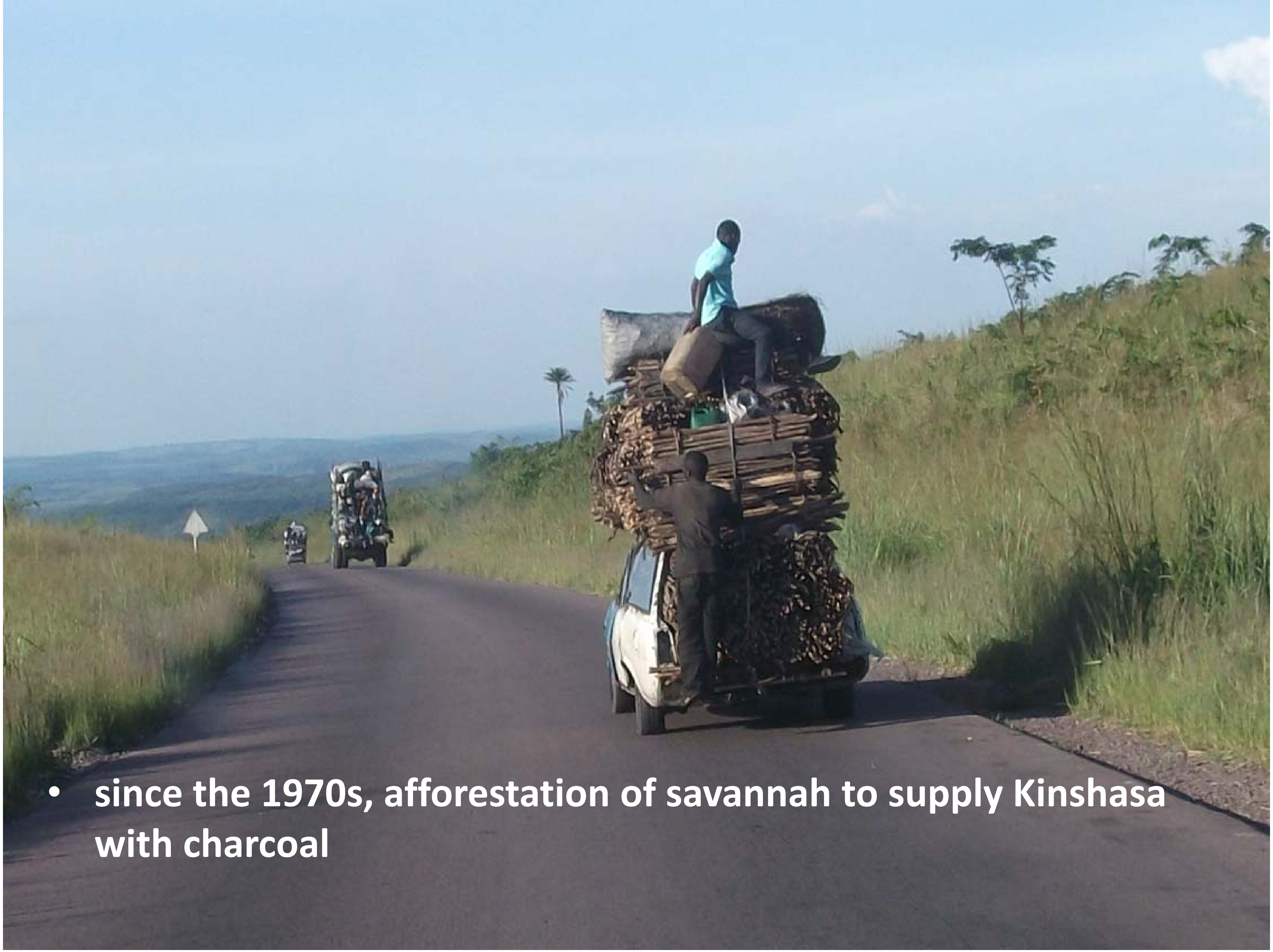

- **since the 1970s, afforestation of savannah to supply Kinshasa with charcoal**


• Agroforestry system = rotational woodlot
• Alternate a phase of food crop production with a phase of fallow planted with N_2 fixing trees
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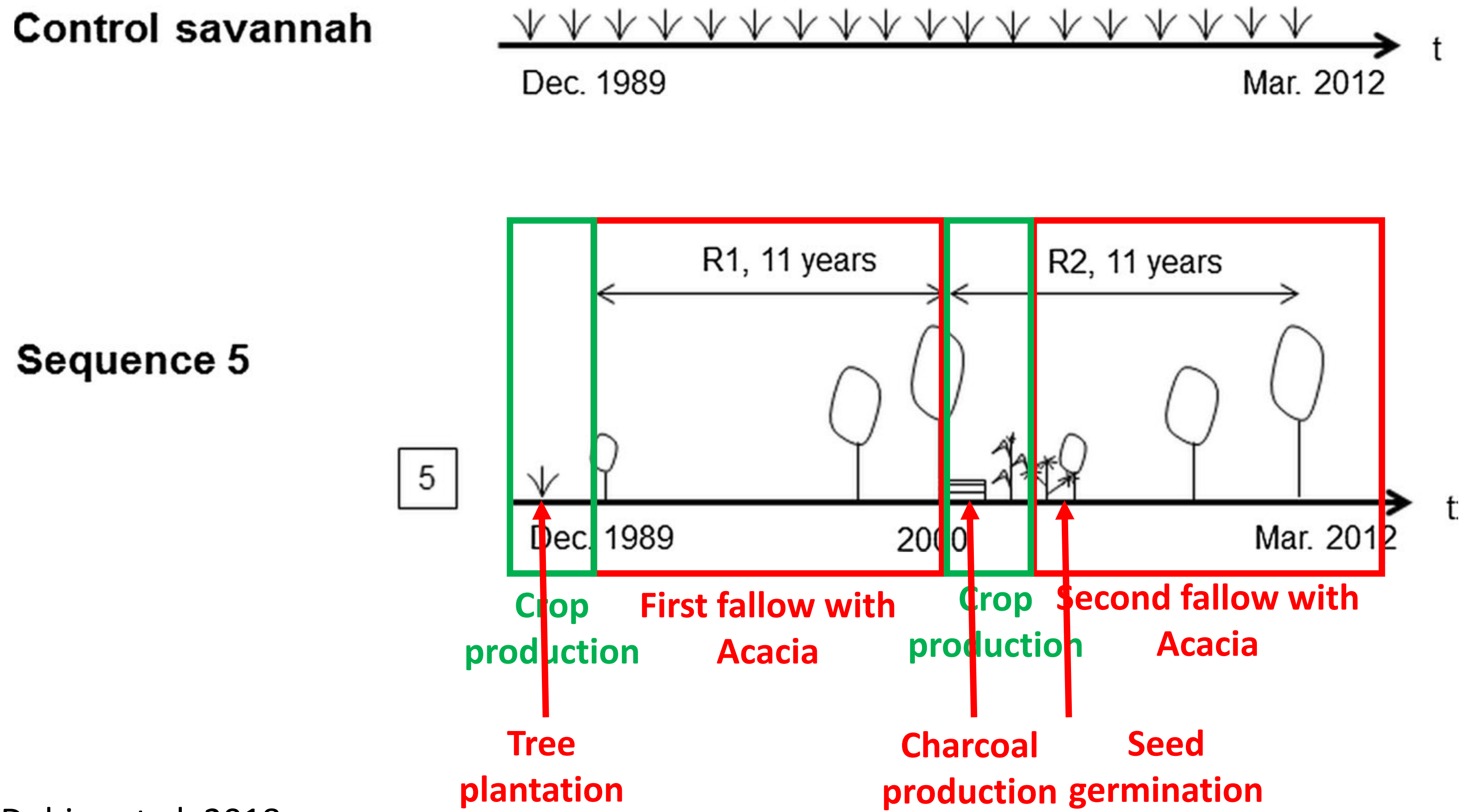
Agroforestry with N fixing trees on the Batéké Plateau in DR Congo



Dubiez et al, 2018


• Cassava or maize production
• Burning of slash residues (leaves, branches, bark)
• Application of ashes of charcoal
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- Charcoal production on-site after Acacia rotation

Agroforestry with N fixing trees on the Batéké Plateau in DR Congo

Sequences	Density (N ha^{-1})		AGB (mg ha^{-1})	Basal area (m^2 ha^{-1})	Mean height (m)
1 (22 years)	239 ± 49	afforestation	83.1 ± 31.6	12.6 ± 3.8	14.9 ± 2.2
2 (1–2 years)	1933 ± 1492		6.2 ± 4.8	2.2 ± 1.7	3.7 ± 1.0
3 (4 years)	2383 ± 1257	2nd fallow	42.7 ± 16.0	9.7 ± 3.5	6.8 ± 2.5
4 (7–8 years)	1256 ± 713		59.5 ± 33.1	12.3 ± 6.0	8.2 ± 2.7
5 (11–12 years)	711 ± 139		41.4 ± 20.6	8.8 ± 3.7	8.5 ± 3.2
6 (1 year)	1372 ± 1153	3rd fallow	1.6 ± 1.7	0.7 ± 0.6	2.9 ± 0.3

Mean ± standard deviation, Density: number of stems ≥ 1 cm in diameter at breast height (dbh: 1.3 m above ground level), Above Ground Biomass (AGB)

Dubiez et al, 2018

Agroforestry with N fixing trees on the Batéké Plateau in DR Congo

- Soil analysis (0-20 cm depth)

	pH in water	C (g kg^{-1})	N (g kg^{-1})	C:N	NH_4^+–N (mg kg^{-1})	NO_3^-–N (mg kg^{-1})	Olsen P (mg kg^{-1})
Savannah	5.2 ± 0.1a	12.4 ± 0.1b	0.6 ± 0.0b	20.9 ± 0.9a	8.8 ± 4.6a	< 0.47b	15 ± 7a

Numbers represent means with standard deviation. Within each column letters indicate differences (ANOVA; $p < 0.05$) between the different treatments

Effect of rotational woodlot in Mampu:

- Increase C sequestration in above-ground biomass
- Increase C, N in soil
- No effect on P in soil
- … but decrease pH and other soil nutrients …

Dubiez et al, 2018

Agroforestry with N fixing trees on the Batéké Plateau in DR Congo

- Soil analysis (0-20 cm depth)

	CEC (cmolc kg^{-1})	Ca (cmolc kg^{-1})	Mg (cmolc kg^{-1})	K (cmolc kg^{-1})	Al (cmolc kg^{-1})
Cobaltihexamine					
Savannah	0.61 ± 0.13c	0.23 ± 0.09a	0.09 ± 0.04a	0.05 ± 0.01a	0.64 ± 0.18b
Sequence 1	0.88 ± 0.02ab	0.08 ± 0.02b	0.02 ± 0.01b	0.03 ± 0.01b	1.14 ± 0.09a
Sequence 2	0.87 ± 0.05ab	0.09 ± 0.04b	0.03 ± 0.00b	0.03 ± 0.01b	1.10 ± 0.08a
Sequence 3	0.84 ± 0.07b	0.08 ± 0.01b	0.03 ± 0.00b	0.03 ± 0.01b	1.02 ± 0.15a
Sequence 4	0.93 ± 0.13ab	0.11 ± 0.05b	0.04 ± 0.01b	0.03 ± 0.00b	1.09 ± 0.08a
Sequence 5	0.97 ± 0.09ab	0.11 ± 0.04b	0.04 ± 0.02b	0.03 ± 0.00b	1.07 ± 0.11a
Sequence 6	1.01 ± 0.08a	0.10 ± 0.04b	0.03 ± 0.01b	0.03 ± 0.01b	1.02 ± 0.09a
Site 1	0.88 ± 0.11a	0.11 ± 0.07a	0.04 ± 0.03a	0.03 ± 0.01a	0.94 ± 0.20b
Site 2	0.86 ± 0.18a	0.12 ± 0.06a	0.04 ± 0.02a	0.03 ± 0.01b	1.08 ± 0.16a

Ways to limit nutrient loss :

- Debark trees on-site before carbonization => Ca inputs
- Return part of the charcoal to the soil => increase pH, decrease Al saturation
- Increase the restitution of leaves, twigs, small branches
- Limestone amendments to increase pH and exchangeable Ca

Dubiez et al, 2018

SOC in agroforestry systems

LETTER

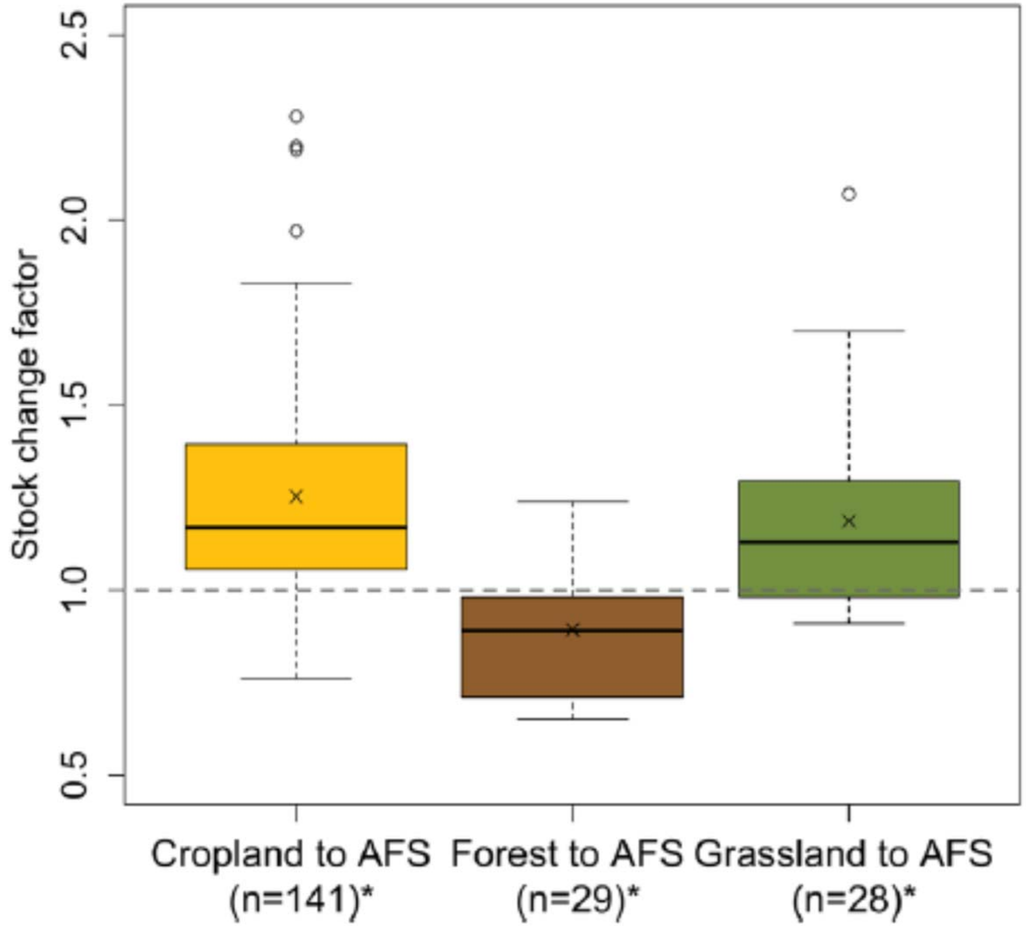
OPEN ACCESS

RECEIVED
9 September 2018

REVISED
22 October 2018

Revisiting IPCC Tier 1 coefficients for soil organic and biomass carbon storage in agroforestry systems

Rémi Cardinael[1,2,3], Viviane Umulisa[4,5], Anass Toudert[4], Alain Olivier[6], Louis Bockel[4] and Martial Bernoux[4]



Cardinael et al, 2018

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SOL et CLIMAT

To be launched on FUN :
www.fun-mooc.fr/universities/Agreenium/
in 2nd quarter of 2021.

Stay tuned !

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Thank you for your attention !

Dr. Julien Demenois (Cirad)